## Chapter 3

## Zooplankton Abundance and Distribution

by

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## SUMMARY


The purpose of this study was to measure the distribution and abundance of invertebrate taxa important in bird and mammal food webs in the Unimak Pass area, and to evaluate these distributions with respect to oceanographic processes and features. Existing information suggested that zooplankton and cephalopods would dominate the invertebrate diets of these animals. However, invertebrate sampling concentrated on only zooplankton because of the difficulty in sampling cephalopods.

Euphausiids and copepods, the zooplankton groups expected to dominate pelagic environments and vertebrate diets, were sampled in the water column and at the surface by nets deployed from aboard the R/V *Miller Freeman*. Sampling was conducted in fall (late September-early October 1986), winter (late February-early March 1987), and spring (late April-early May 1987) along cruise transects through the Unimak Pass area.

Estimates of invertebrate wet-weight biomass and composition by major taxa (e.g., copepods, euphausiids) and temporal and spatial trends in abundance (biomass) were described.

Major findings and their implications are as follows:

(1) Proportions of the total biomass that major zooplankton groups contributed varied seasonally. Gelatinous zooplankton (jellyfish) dominated spring catches northeast of Unimak Pass in the vicinity of the well-known "slime bank" on the North Aleutian Shelf, but was inconsequential in other seasons and places. Euphausiids formed the overwhelming majority of non-gelatinous zooplankton biomass during fall and winter, and a slight majority in spring. Copepods were scarce in fall and winter but nearly equalled the biomass of euphausiids in spring.

All these abundance patterns were predictable to some extent. Jellyfish are frequently found to be abundant northeast of Unimak Pass. Euphausiids always tend to increase in dominance over the shorter-lived copepods in winter, and spring blooms of copepods typically cause their biomass to increase in proportion to that of slower-reproducing taxa.

(2) Spatial patterns of biomass distribution of euphausiids changed markedly between the fall and remaining cruises. During fall, euphausiids were widely distributed except in

the Alaska Coastal Current, and the highest biomasses were found in the Gulf of Alaska Water north of the Krenitzin Islands. Winter and spring locations of high biomass levels were remarkably similar with highest biomasses being in the Alaska Coastal Water (north). Clusters of high biomass were within 50 km of land a) immediately west of Unimak Island, b) in the Krenitzin Islands, and c) southeast of the Krenitzins.

(3) Relative proportions of euphausiid biomass in the water column vs. at the surface varied seasonally. Euphausiids were much more common in the water column in winter than they were at the surface; this pattern reversed in spring. This pattern was also somewhat predictable, because euphausiids are known to gather in breeding swarms at the surface in spring.

(4) In fall and winter, copepod scarcity masked any clear patterns of their biomass distribution in space, but in spring, large biomasses appeared at this time west of Unimak Island in a "corner" of the shelf break. This area corresponds to a region that appears to receive an influx of nutrients upwelled at passes in the Aleutian chain west of the unimak Pass area but transported eastward along the north side of the Aleutians to the shallow waters north of Unimak Island. Secondary peaks in abundance were in the Unimak Pass proper/Krenitzin Islands area. Surface and water-column centers of abundance generally coincided in space.

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## INTRODUCTION

One of the objectives of the Unimak Pass study was to relate the seasonal distributions, abundances, and activities of marine bird and mammal species to insular and persistent oceanographic features such as currents, tide rips, and upwelling areas. The rationale for this objective was that birds and mammals had been observed to sometimes concentrate in apparent response to such oceanographic phenomena. It has been hypothesized further that this concentrating behavior might be in response to locally high densities of invertebrate components of food webs caused by ocean fronts or sites of upwelling. Studies of invertebrates were therefore designed to measure the distributional abundances of taxa important in vertebrate food webs and to relate these distributions to oceanographic processes or features.

## CURRENT STATE OF KNOWLEDGE

Extensive sampling for invertebrates in the eastern Aleutian Islands and Unimak Pass has been in the past largely restricted to commercially-important species, mainly crabs. But sampling of other groups has been carried out in nearby regions of the Bering Sea and North Pacific, and the results suggest much about the invertebrate communities that exist in the study area. Thus the following discussions are based on information collected both within the study area and in nearby areas. Emphasis is on those invertebrate groups important to vertebrate consumers—zooplankton (copepods, euphausiids) and nektonic cephalopods (squids). Most of the information on non-commercial species comes from the recent study of the North Aleutian Shelf (LGL 1987).

### Zooplankton

Very little sampling for zooplankton has been conducted in the Unimak Pass area, but general circulation patterns (see Schumacher et al. 1982, Hood 1986) suggest that the communities from the study area should resemble those of nearby shelf and oceanic waters. Zooplankton sampling has been most prevalent on the adjacent North Aleutian Shelf (NAS) and other areas of the Bering Sea. The following discussions are mainly drawn from Thomson (1987), and other studies in the southeastern Bering Sea.

Zooplankton biomass measured on the NAS during 1984 and 1985 was extremely low compared with that of offshore Bering Sea shelf waters, other arctic waters, and other marine waters in general (Thomson 1987). Other Bristol Bay nearshore waters are, like the NAS, typically low in zooplankton biomass. Total zooplankton biomass on the NAS was found by Thomson (1987) to be highest in June and July. The biomass peak on the NAS and other inshore areas (July/August) was later than that on the outer shelf (May) or middle shelf (early June). Biomass on the NAS was lowest in September, probably as a result of jellyfish predation.

Relative abundances among zooplankton taxa changed among seasons on the NAS (Thomson 1987). Chaetognaths were the dominant invertebrate taxon in winter, but decreased in abundance through spring and summer. Copepods generally increased in abundance from a January low to a late spring (May) high, sometimes remaining abundant into late summer. Abundance of euphausiids showed no marked seasonal differences. Decapod larvae and fish larvae both increased in absolute biomass from a January low to a July high. Carnivorous zooplankton were dominant in winter; the abundance of herbivores began increasing in April with onset of the spring bloom, and generally increased through July.

The most important zooplankton taxa in terms of their apparent importance to vertebrate food chains in the southeastern Bering Sea are copepods and euphausiids (see Craig 1987, Troy and Johnson 1987a,b). Information on these and other groups follow.

**Copepods**

The eastern Bering Sea has been depicted as having two major copepod communities, an oceanic and outer-shelf (oceanic) community and a middle-shelf and coastal (shelf) community. These may mix to some extent along the outer shelf, and probably in the Unimak Pass area as well. Near the coast, a distinct nearshore community may also occur. These communities are found consistently in hydrographically-defined domains (Cooney 1981).

The oceanic community is dominated by the large copepods (*Calanus cristatus*, *C. plumchrus*, *Eucalanus bungii*, and *Metridia pacifica*) that overwinter at ocean depths beyond the shelf edge and migrate upward in large numbers in spring to take advantage of phytoplankton blooms at the surface. The shelf community is dominated by the small copepods (*Acartia longiremis*, *Pseudocalanus* spp., and *Oithona similis*) that overwinter on the shelf and survive in low numbers until spring. Shelf waters adjacent to ocean depths contain a mixture of these dominants, at least in summer. Motoda and Minoda (1974) note that a copepod, *Centropages abdominales*, described by Cooney (1981) as a nearshore species, is abundant in the shallow waters around Unimak Pass.

Because there has been limited zooplankton sampling in the past in the Unimak Pass area, it has not been clear whether the copepod community is more typically an oceanic or a shelf type. Discussions by Smith and Vidal (1986) on the transport of oceanic forms onto the outer portion of the southeastern Bering Sea shelf lend support to the idea that oceanic-type copepods might dominate in western parts of the Unimak Pass area because of the proximity of deep waters and the probable strong effect of upwelling.

But because of the effect of the Alaska Coastal Current near Unimak Island on the east side of Unimak Pass (Schumacher et al. 1982), shelf copepods might be expected to be dominant there.

Cooney (1978, 1981) and Smith and Vidal (1986) discuss the tendency for spring-summer standing crops of, and production by, copepods to be relatively large in outer shelf and shelf break waters of the southeastern Bering Sea. This high production is attributed to two interacting factors. First, spring and summer phytoplankton production is relatively high in the shelf break area, probably enhanced by nutrients upwelling from depth. Second, the shelf break and outer shelf copepod communities are dominated by oceanic species that overwinter (and reproduce) at depth and move to the surface in sufficient numbers in spring to consume most of the primary production. In contrast to conditions on the outer shelf and break, the inner shelf copepods greet the spring plankton bloom in low numbers, consuming only a small proportion of the primary production.

Because high primary production and dominance by oceanic copepods may characterize at least the western portions of the Unimak Pass area, high copepod productivity may occur in much of that area. By similar logic, one would expect the more eastward pass areas near Unimak Island to have relatively low copepod production and biomass, given that shelf waters and shelf copepods may dominate that area.

**Euphausiids**

Smith and Vidal (1986) believed that euphausiids are prominent in southeastern Bering Sea food webs. Craig (1987) and Troy and Johnson (1987a) found euphausiids to dominate diets of many fishes and birds on the North Aleutian Shelf. Essentially no information about their importance to vertebrates in Unimak Pass is available in the literature.

Similarly to copepods, euphausiids in the southeastern Bering Sea appear to be distributed according to major hydrographic domains. It has been generally agreed that two communities exist—an oceanic community occupying the outer shelf, shelf break, and oceanic waters, and a shelf community found in the middle shelf and coastal waters. A "mixed" community occupies a zone of overlap on the outer shelf (Motoda and Minoda 1974).

Reasons for this segregation of euphausiid communities have not been as clearly explained as they have been for the copepod communities. Motoda and Minoda (1974) note that *Thysanoessa longipes* prefers higher-salinity water than *T. raschii*; but over large parts of the range of *T. raschii* in the middle and inner shelf of the southeastern Bering Sea, salinities are not appreciably different from those of the oceanic and outer shelf areas dominated by *T. longipes*. Perhaps temperatures in winter habitats are a crucial factor, as they are with copepods.

The dominant euphausiids of the oceanic community are *Thysanoessa longipes* and *T. inermis;* the dominant species of the shelf community is *T. raschii* (Motoda and Minoda 1974, Minoda and Marumo 1975, Cooney 1981). Few reports specifically characterize the euphausiid community of the Unimak Pass area, though it appears likely that both oceanic and shelf species occur in the study area. Oceanic species may dominate in more westerly parts of the study area because of the nearness of the deep ocean environment and the apparent prevalence of upwelling. Shelf species may be common in eastern parts because of the probable influence of the Alaska Coastal current.

Dagg (1982) showed that, in the southeastern Bering Sea, *Thysanoessa* individuals eat mostly phytoplankton, but they can derive most of their energy requirements from phytoplankton only if the phytoplankton standing stocks reach bloom levels. At sub-bloom levels, they consume more copepods and other crustaceans, and fish and invertebrate eggs. Because they are more readily omnivorous than copepods, their standing stocks exhibit less drastic depressions between phytoplankton bloom periods than do stocks of copepods.

Dagg (1982) maintained that euphausiids are probably not sufficiently abundant to contribute prominently to Bering Sea carbon budgets. However, Motoda and Minoda (1974), Craig (1987), and Troy and Johnson (1987a) noted that they are important as foods of Bering Sea fishes and birds. Further, Minoda and Marumo (1975) found euphausiids to be an important part of the standing stock of zooplankton in the Bering Sea. Motodo and Minoda (1974) believed that their low biomass representation in many sampling efforts may simply have been caused by avoidance of sampling nets.

Euphausiids in general, and *Thysanoessa* in the Bering Sea (Dagg 1982), tend to aggregate in swarms, to become stratified in the water column, and to migrate vertically on a diurnal cycle. Typically, *T. raschii* and *T. inermis* migrate toward the surface at night and to the bottom during daylight hours (Dagg 1982), except during the breeding season in late spring and early summer, when they may swarm at the surface both day and night (Ponomareva 1966).

**Other Zooplankton**

Other important components of the zooplankton community in the southeastern Bering Sea, and possibly of the Unimak Pass area as well, are pelagic (mainly hyperiid) amphipods and chaetognaths. Hyperiid amphipods are important prey of vertebrates, and chaetognaths are major predators of other zooplankton. *Parathemisto* is the major amphipod, with *P. pacifica* occurring largely in the outer shelf and oceanic areas and *P. libellula* assuming dominance in middle shelf and coastal areas (Motoda and Minoda 1974, Cooney 1981). Among the chaetognaths, *Sagitta elegans* is abundant in the oceanic and all shelf zones; *Eukrohnia hamata* is also common in the oceanic realm (Cooney 1981).

Both the amphipod *Parathemisto* and the chaetognath *Sagitta* are largely carnivorous; in and near the study area they probably feed mainly on copepods. *Parathemisto* is an important food source for some vertebrates, particularly birds (e.g., Short-tailed Shearwaters and, to a lesser extent, murres and Black-legged Kittiwakes—Hunt et al. 1981); *Sagitta* is seldom listed as an important food item for vertebrates.

### Summary

The Unimak Pass zooplankton community is likely to exhibit similarities to those of surrounding waters because of the existing circulation patterns and the tendency for zooplankton to be more-or-less passively transported. Most data are available from the nearby southeastern Bering Sea, where the two principal zooplankton communities have been aptly described by Cooney (1981) as (1) an oceanic and outer-shelf community dominated by large, interzonal copepods, the hyperiid amphipod *Parathemisto pacifica*, the chaetognaths *Sagitta elegans* and *Eukrohnia hamata*, and the euphausiids *Thysanoessa longipes* and *T. inermis*; and (2) a middle-shelf and coastal community dominated by small copepods, the amphipod *Parathemisto libellula*, the chaetognath *Sagitta elegans*, and the euphausiid *Thysanoessa raschii*. Between the relatively stable middle-shelf water and that of oceanic origin, the zooplankton community becomes a mixture of shelf and oceanic species. Because the waters of Unimak Pass are very near the southeastern Bering Sea and exhibit some qualities of both outer-shelf and coastal areas, it is likely that Unimak Pass zooplankton communities also include representatives from both these domains.

## Cephalopods

Squids and octopuses are of considerable importance to vertebrate consumers, particularly mammals, in the southeastern Bering Sea, the northern Gulf of Alaska, and probably in Unimak Pass (Fiscus 1982, Lowry et al. 1982). Existing information about their populations and their trophic significance comes largely from areas adjacent to Unimak Pass, and even these data are scarce.

### Squid

Wilson and Gorham (1982a), referencing Okutani (1977), indicate that at least 10 species of squid are relatively abundant in the Bering Sea and/or the northern North Pacific. Ronholt et al. (1986) note that the red squid, *Berryteuthis magister*, accounted for nearly 85% of the total squid biomass in demersal trawl catches in the Aleutians from Attu to Unimak Pass.

Most information on squid distribution near the Unimak Pass area has been obtained from stomach analyses of whales, seals, and salmon (Wilson and Gorham 1982a). This information suggests that squid concentrate in areas with abrupt changes in depth, in areas of upwelling along the continental slope or slopes of underwater ridges, near oceanic islands, and in areas of convergence and divergence (Wilson and Gorham 1982a, quoting Lipinski 1973, and Okutani and Nemoto 1964). The Unimak Pass area would therefore appear to be excellent habitat for squids.

Wilson and Gorham (1982a) examined records of individual catches of squids by National Marine Fisheries Service (NMFS) trawling and by foreign fleet trawling and seining in the southeastern Bering Sea and the northern Gulf of Alaska. High catches of the squids *Berryteuthis magister*, *Onychoteuthis banksii*, and unidentified squids were clustered along the southeastern Bering shelf break and slope and along the Aleutian chain. This reflected to some extent the areas receiving greatest fishing pressure, but probably also showed squid habitat preferences for these areas. Highest abundances of squids caught by trawl in 1980 were near passes in the eastern and western Aleutians.

Fiscus (1982) observed a pattern in the diets of marine mammals that may suggest something about squid distribution in the Unimak Pass area. He noted that, over the continental shelf, fish were more common than squids in mammal diets, but that over the continental slope and in the deep seas, squids became much more important.

Squids are major foods for many mammal species. Most of the small cetaceans, several of the large cetaceans, and most pinnipeds prey on squids (Fiscus 1982). Fiscus noted that most marine mammals that forage along the continental slope or in the deeper oceanic waters of the North Pacific Ocean and Bering Sea have squids as major parts of their diets.

**Octopus**

Use of octopuses as important prey by marine mammals and other vertebrates in the southeastern Bering Sea has been noted by several authors (Feder and Jewett 1981, Fiscus 1982, Lowry et al. 1982). It is likely that octopuses may be used by these vertebrates in the Unimak Pass area.

The distribution and abundance of octopuses in and near Unimak Pass are difficult to determine from existing data. Analyses of NMFS trawl survey data, observations of divers and biologists, and foreign fleet catch data from the northern Gulf of Alaska and the southeastern Bering Sea (Wilson and Gorham 1982b) show octopuses to have somewhat similar distributions to squids in these areas—catches seem to be concentrated along the Bering shelf break, with sporadic catches in the eastern Aleutians.

Ronholt et al. (1986) found octopuses occurring at low densities (relative to squids) throughout the eastern Aleutians; densities were somewhat higher immediately north of the study area in the Bering Sea at 1-200 m depths. The historical octopus catch (trawls and crab pots) in the eastern Aleutians has been generally small and variable among years (ADFG 1985). Identified species in the catch included *Octopus dolfeini* (the giant Pacific octopus) and *Opisthoteuthis californiana* (the flap-jack devilfish).

## METHODS

Sampling for zooplankton was done at night at a series of stations along the survey lines censused for marine birds and mammals the preceding (or sometimes the following) day. Locations of zooplankton sample sites are shown in Figures 1-3. Listings of all zooplankton samples are found in Chapter 10 (Appendix C-1, C-2, C-3).

Zooplankton samples were collected by oblique tows with paired (505μ and 333μ) 0.6-m-diameter bongo nets. Nets were equipped with General Oceanics 2030 flowmeters. The oblique tows sampled the water column to a maximum of 200 m.

Another set of samples was collected from the surface waters. Initially a Tucker trawl was used for sampling this zone but after the net was irreparably damaged, bongo nets were used for this purpose as well.

As the nets were lifted from the water they were hosed down with seawater to move all the zooplankton into the cod end cups. The 505μ mesh cup was emptied into a fine net, the excess water was gently squeezed out, and the solid material was transferred to a graduated cylinder where the zooplankton volume was measured by displacement. The volumes of large organisms (>0.1ml), such as fish, were measured separately. In the case of gelatinous plankton (jellyfish), the gelatinous material was separated from the other zooplankton and the volume measurements were made separately.

After the volume measurement was complete, the non-gelatinous portion of the sample was examined and subdivided if necessary, and a visual estimate of taxonomic composition was made. The initial step was to remove any large or scarce organisms, which were counted and recorded separately. The remainder was split into approximately equal groups by dividing the pile of organisms in a Petri dish into halves, quarters, or eighths. One of the piles was then sorted by major taxonomic group (copepod, amphipod, euphasiid,

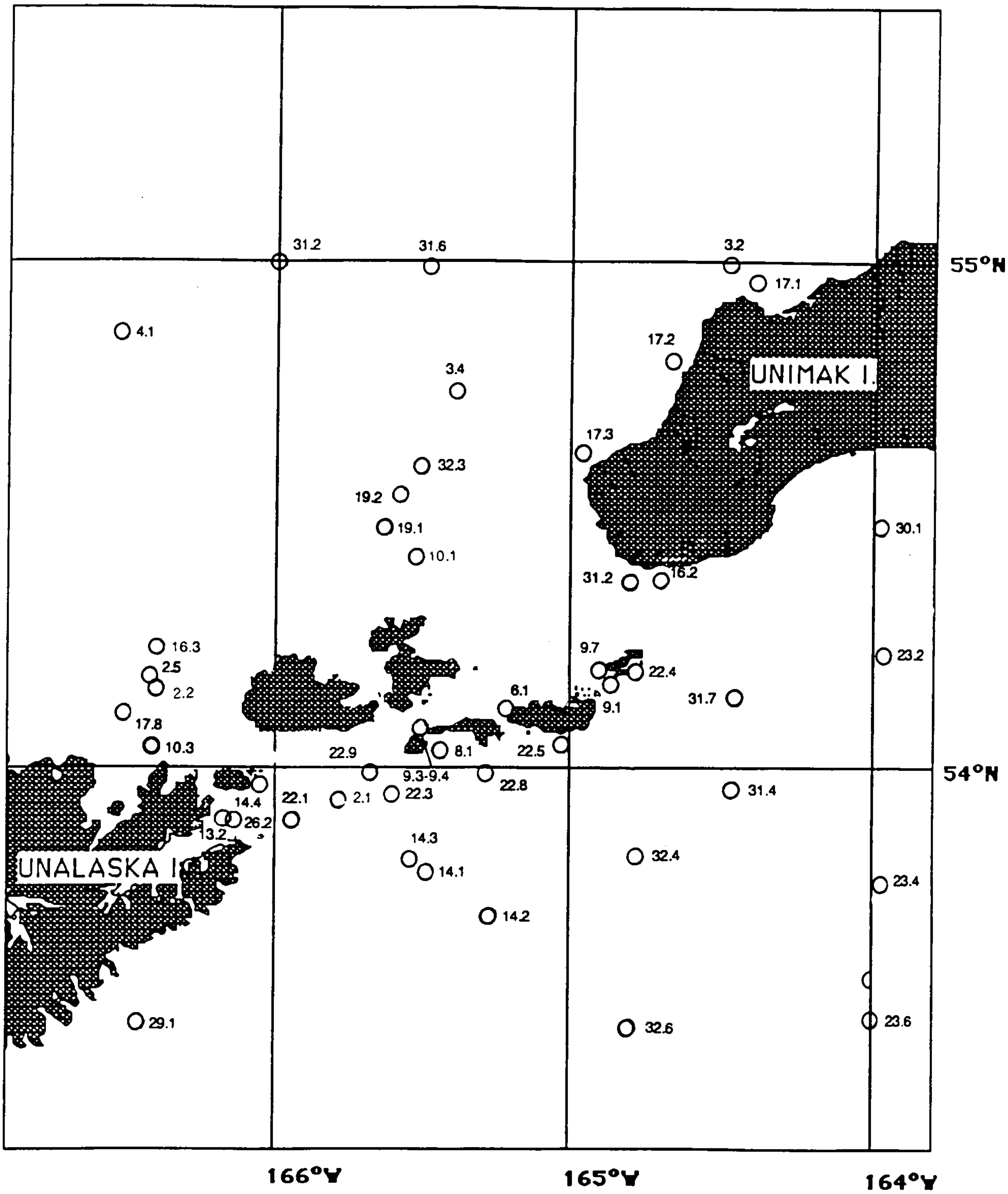


Figure 1. Locations of zooplankton sampling stations during fall 1986, Unimak Pass area, Alaska.

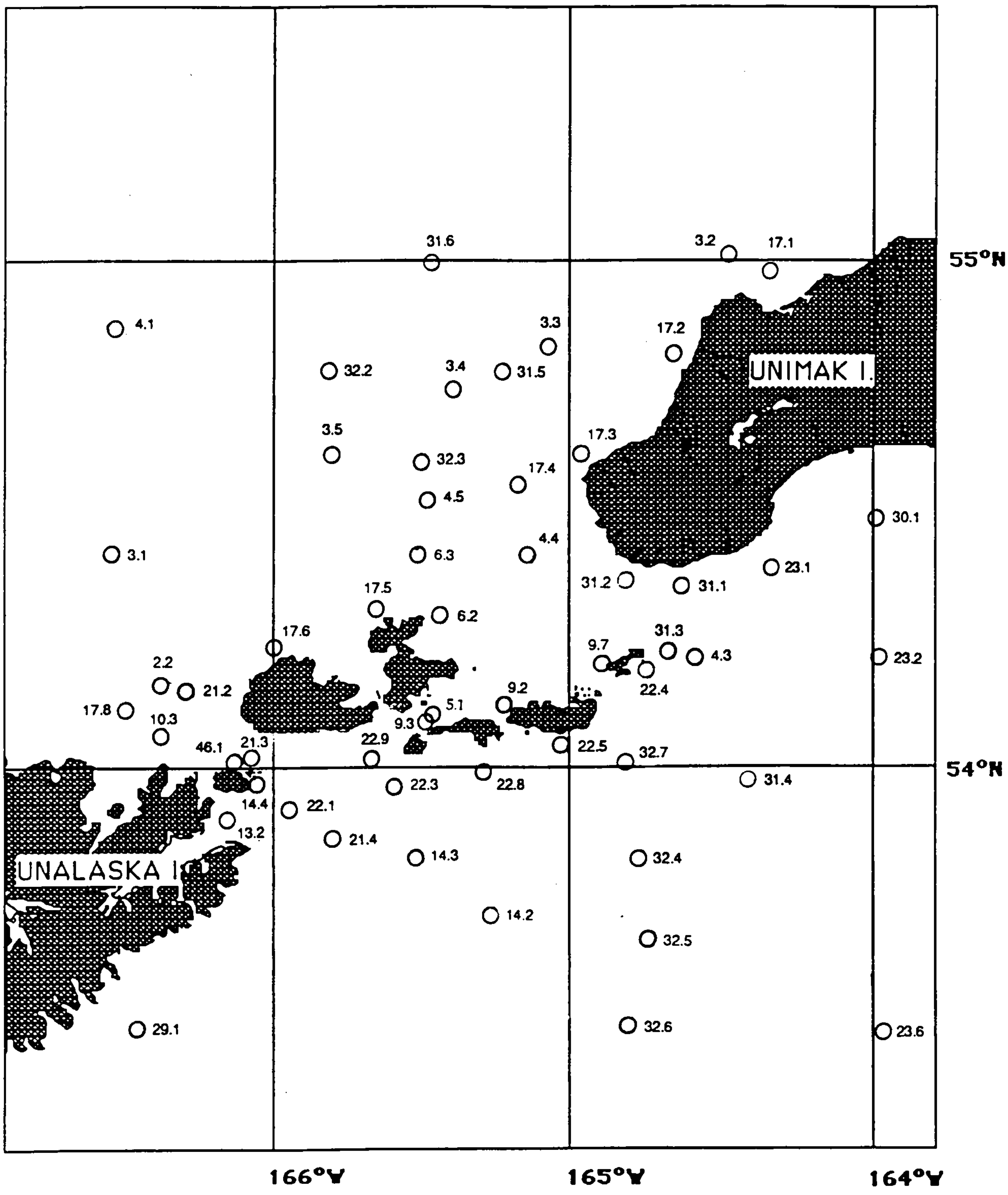


Figure 2. Locations of zooplantkton sampling stations during winter 1987, Unimak Pass area, Alaska.

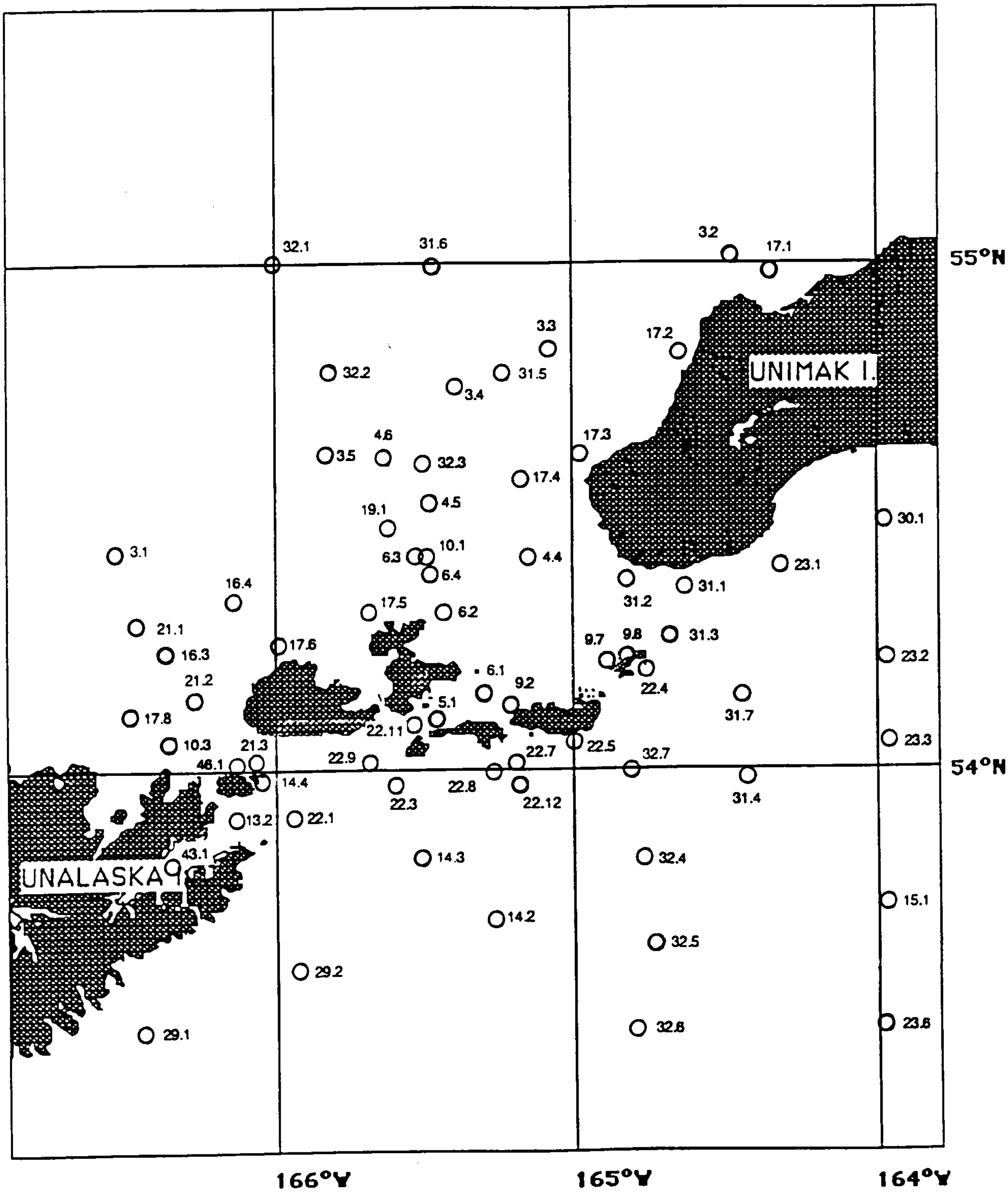


Figure 3. Locations of zooplankton sampling stations during spring 1987, Unimak Pass area, Alaska.

cephalopod, pteropod, chaetognath, larval fish, ctenophore) and the relative wet-weight biomass of each sorted group was estimated and recorded as percent composition for that level of subdivision. The biomass of each group was estimated as:

$$\text{biomass } (g/m^3) = \frac{\text{total sample volume (ml) x proportion taxon}}{\text{volume water filtered}}$$

The entire sample (minus jellyfish) was preserved in formalin.

## RESULTS

Distributional abundances of zooplankton as indicated by surface and water-column sampling are presented below. Because devices capable of effectively sampling other invertebrates (e.g., cephalopods) were not employed, data about those groups are not presented. As will be shown, euphausiids and copepods dominated the invertebrate samples, so the main focus is on these groups.

### General Biomass Distribution and Composition

Biomass estimates ($g/m^3$ wet wt) of invertebrates in the surface layer (data from surface tows) and integrated over the water column (data from oblique tows) are presented in this section. Biomass estimates are segregated by the water mass (Fig. 4) in which the samples were taken. Descriptions of these water masses and their temporal changes in spatial extent can be found in Chapter 2 (PHYSICAL PROCESSES AND HYDROGRAPHY) of this report.

**Fall**

Fall biomass estimates for euphausiids, copepods, and total zooplankton at the surface and in the water column of the major water masses, based on average catches within each water mass, are shown in Figs. 5 and 6. Isolines of zooplankton biomass, based on catches at each station, appear in Figs. 7 and 8.

Total zooplankton biomass in the water column was generally greatest immediately northwest of Akutan Pass (Fig. 7), but spots of local abundance appeared elsewhere. No clear association of biomass levels with any particular water mass was evident, although markedly higher biomasses were recorded in the GAWn (approximately double that of most other areas). The Alaska Coastal Current, especially the southern portion, supported very low biomasses of invertebrates. Euphausiids comprised by far the highest proportion of the total in all areas except the ACW where gelatinous zooplankton predominated.

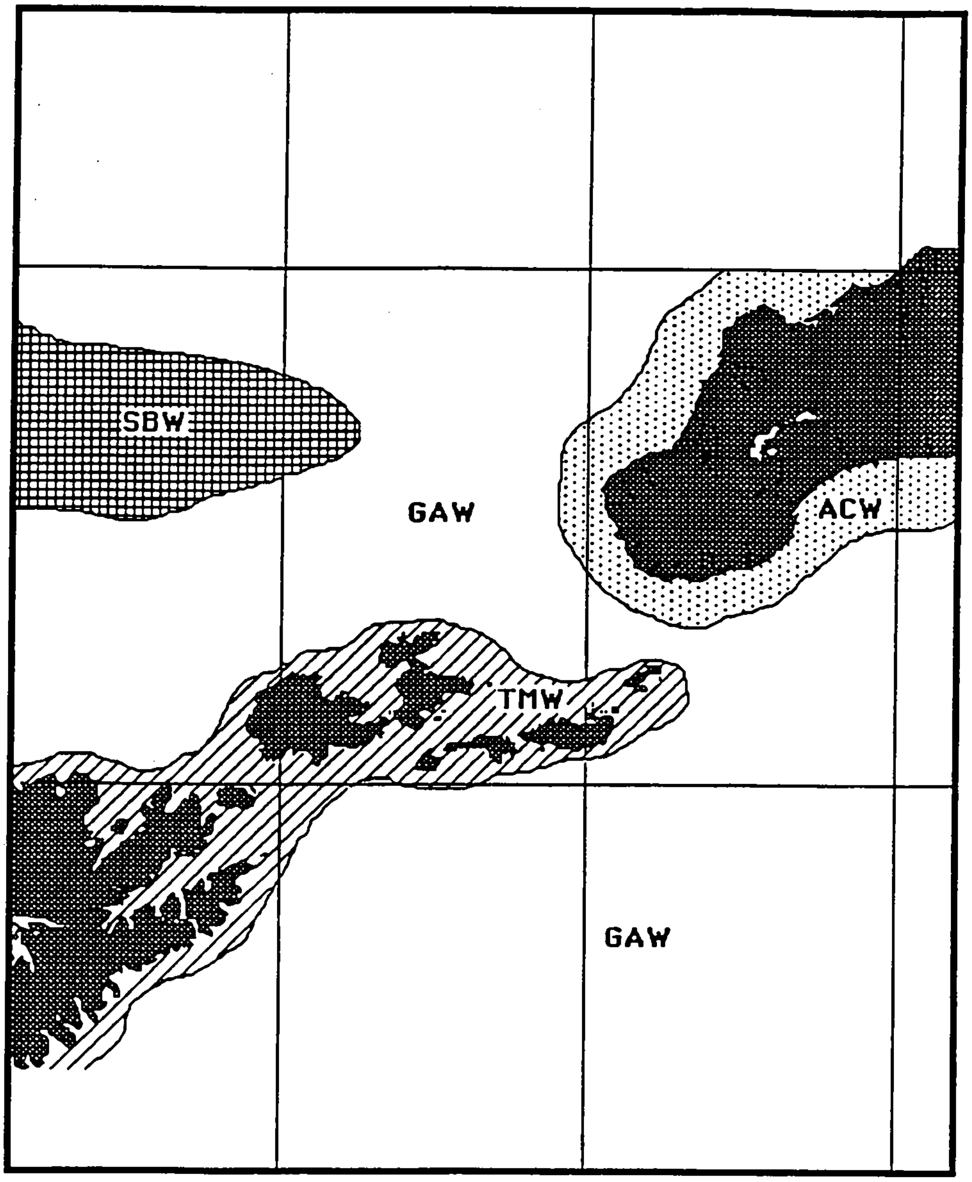


Figure 4. Schematic map of the principal water masses in the Unimak Pass area, Alaska (ACW=Alaska Coastal Water; GAW=Gulf of Alaska Water; SBW=Shelf Break Water; TMW=Tidally-mixed Water). Actually boundaries varied among cruises.

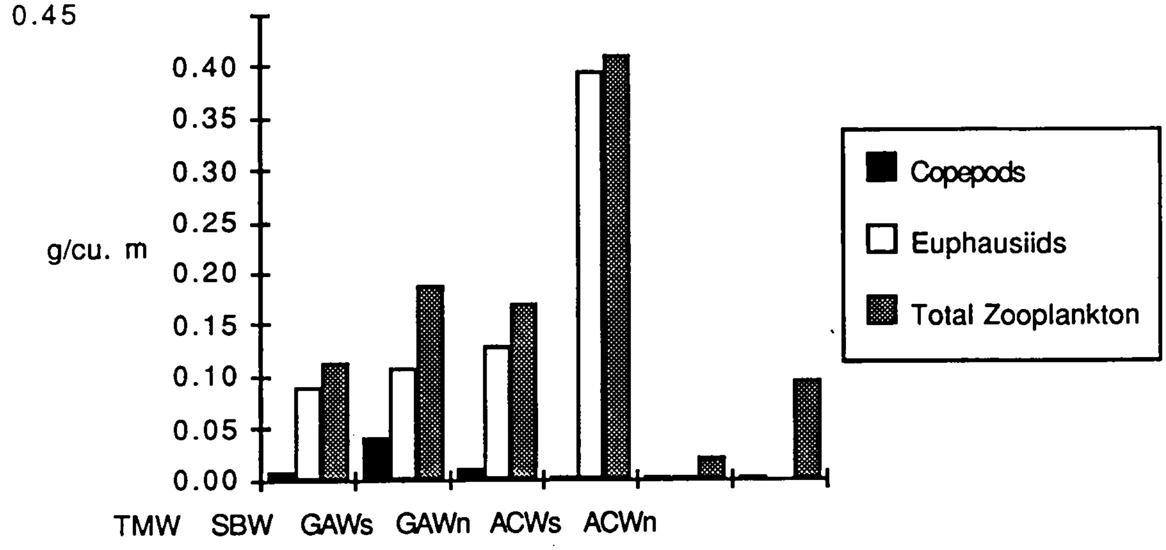


Figure 5. Abundances of zooplankton groups (grams per $m^3$) in the principal water masses during fall as determined by oblique tows. TMW = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

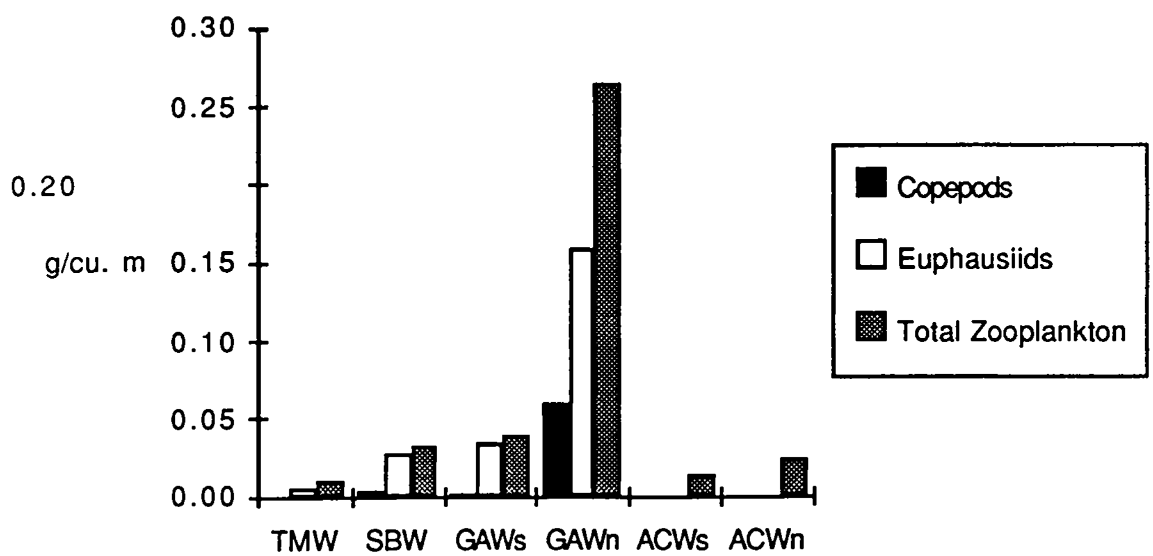


Figure 6. Surface abundances of zooplankton groups (grams per $m^3$) in the principal water masses during fall as determined by surface Tucker trawls, Unimak Pass area, Alaska. TMW = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

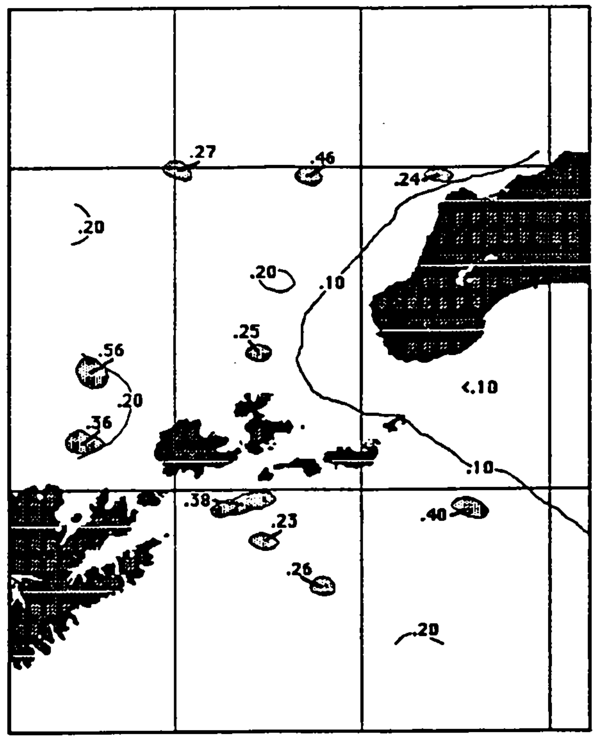


Figure 7. Isolines of total water-column zooplankton abundance (grams/m$^3$) as determined by oblique tows during fall in the Unimak Pass area, Alaska.

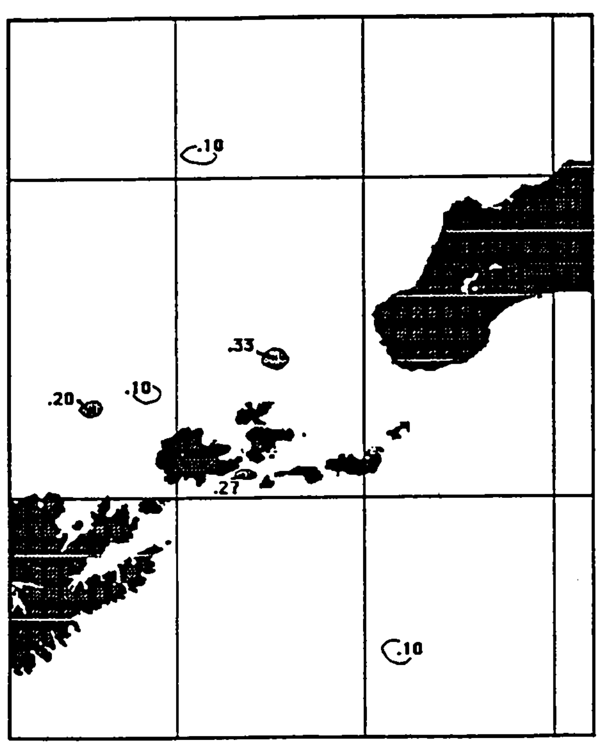


Figure 8. Isolines of total surface zooplankton abundance (grams/m$^3$) as determined by tucker trawls during fall in the Unimak Pass area, Alaska.

Zooplankton surface biomass was highest in the GAWn, especially north of Unimak and Akutan passes (Fig. 6). Elsewhere, except for an isolated high catch in Avantanak Strait, surface zooplankton were scarce. Except in the ACW where gelatinous zooplankton predominated, euphausiids comprised by far the highest proportion of surface biomass totals.

On average, both euphausiid and total zooplankton biomass levels per unit water volume were far greater in subsurface than in surface waters (compare Figs. 5 and 6).

**Winter**

Winter biomass estimates for euphausiids, copepods, and total zooplankton at the surface and in the water column of the major water masses, based on average catches within each water mass, are shown in Figs. 9 and 10. Isolines of zooplankton biomass, based on catches at each station, appear in Figs. 11 and 12. General patterns of winter abundance of zooplankton are discussed below.

Total zooplankton biomass in the water column was generally greatest immediately west and northwest of Unimak Island (Figs. 9 and 11), but spots of local abundance appeared elsewhere. No clear association of biomass levels with any particular water mass was evident, although the deepest areas and those farthest to the southeast had lowest biomasses. Euphausiids comprised the highest proportion by far of the total in all areas.

Zooplankton surface biomass was greatest in offshore areas south of Unimak Pass (Figs. 10 and 12). On average and in most water masses, euphausiids comprised by far the highest proportion of surface biomass totals; this group was responsible for the anomalously high total surface biomass south of the pass.

On average, both euphausiid and total zooplankton biomass levels per unit water volume were far higher in subsurface than in surface waters (compare Figs. 11 and 12). Zooplankton biomasses were low in surface waters north and northwest of Unimak pass and relatively high south of the pass; the converse distributional trend was evident in subsurface waters.

**Spring**

Spring biomass estimates for euphausiids, copepods, and total zooplankton at the surface and in the water column of each major water mass are shown in Figs. 13 and 14. Isolines of total zooplankton biomass, based on catches at sampling stations, are shown in Figs. 15 and 16. Patterns of spring

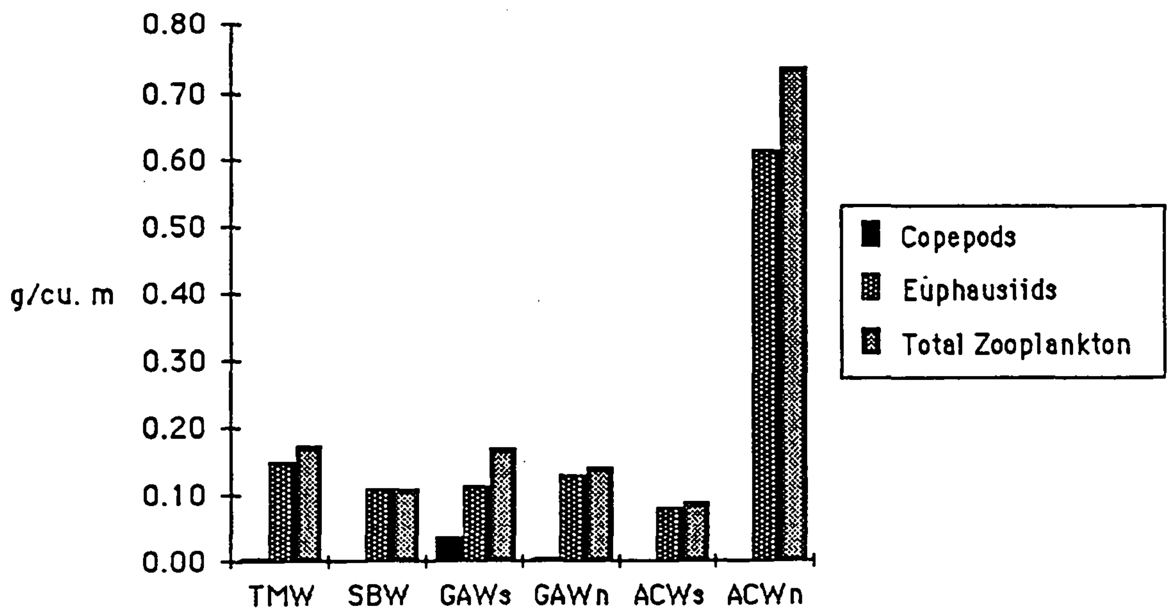


Figure 9. Water-column abundances of zooplankton groups (grams/$m^3$) in the principal water masses during winter as determined by oblique tows, Unimak Pass area, Alaska. TMV = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

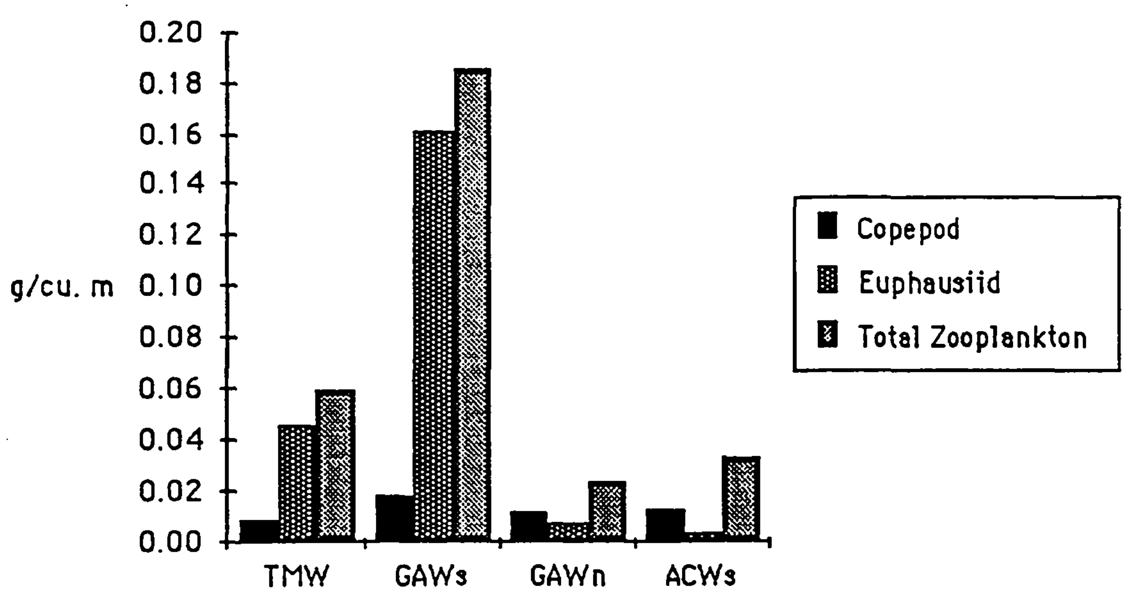


Figure 10. Surface abundances of zooplankton groups (grams/$m^3$) in the principal water masses during winter as determined by surface bongo tows, Unimak Pass area, Alaska. TMV = Tidally-mixed Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south).

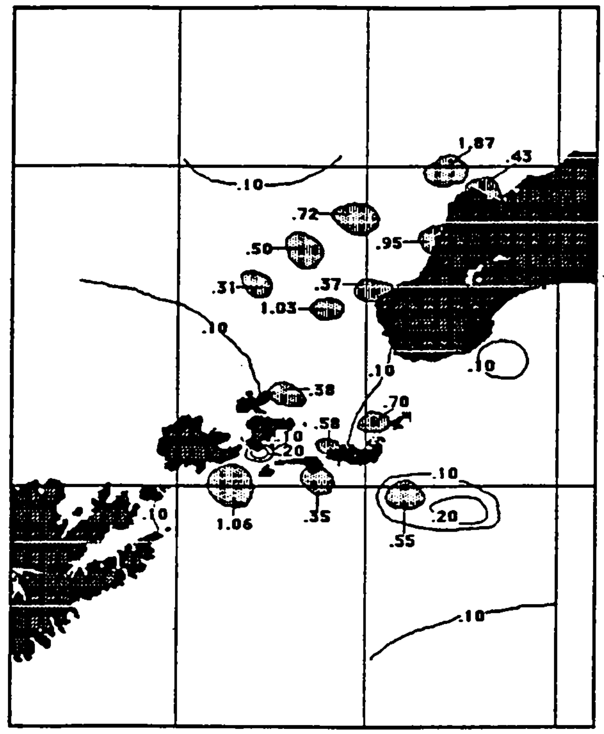


Figure 11. Isolines of total water-column zooplankton abundance (grams/m$^3$) as determined by oblique tows during winter in the Unimak Pass area, Alaska.

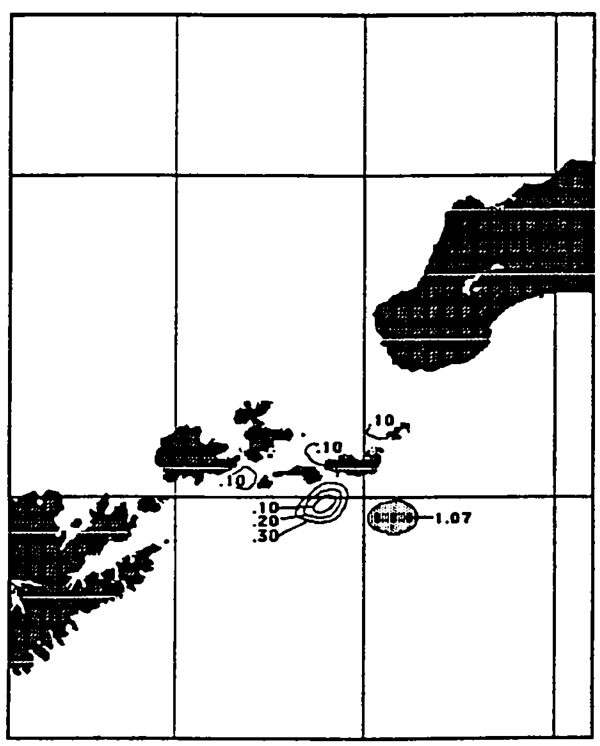


Figure 12. Isolines of total surface zooplankton abundance (grams/m$^3$) as determined by bongo tows during winter in the Unimak Pass area, Alaska.

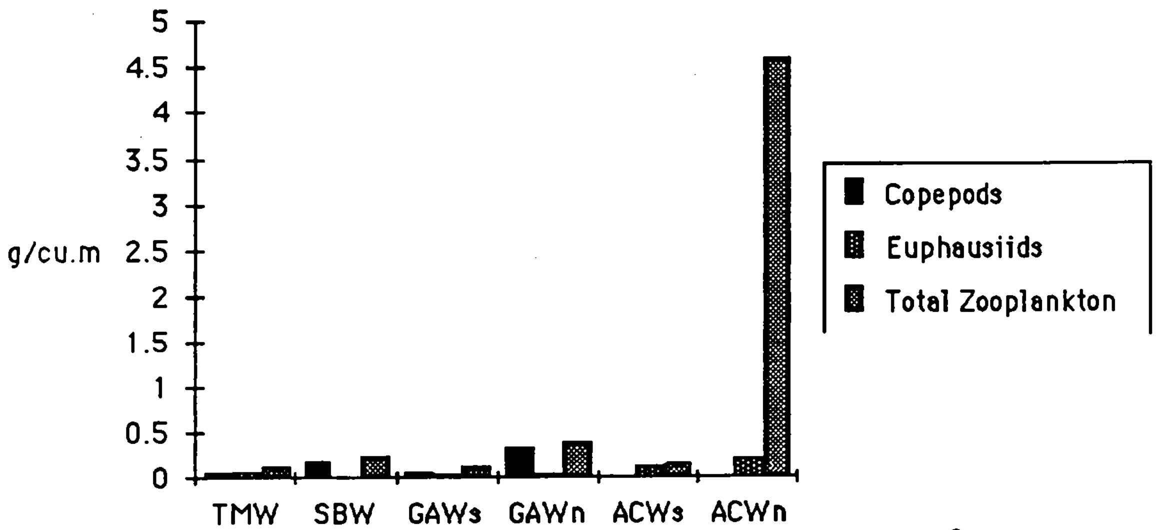


Figure 13. Water-column abundances of zooplankton groups (grams per $m^3$) in the principal water masses during spring as determined by oblique tows, Unimak Pass area, Alaska. TMW = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

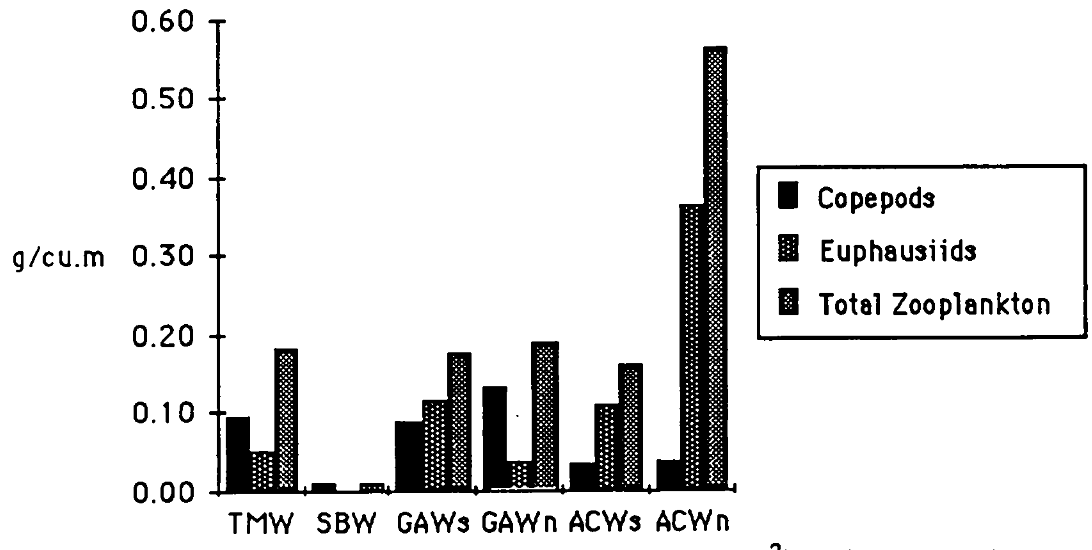


Figure 14. Abundances of zooplankton groups (grams per $m^3$) in the principal water masses during spring as determined by surface tows, Unimak Pass area, Alaska. TMW = Tidally-mixed Water; SBW = Shelf Break Water; GAW = Gulf of Alaska Water (s=south, n=north); ACW = Alaska Coastal Water (s=south, n=north).

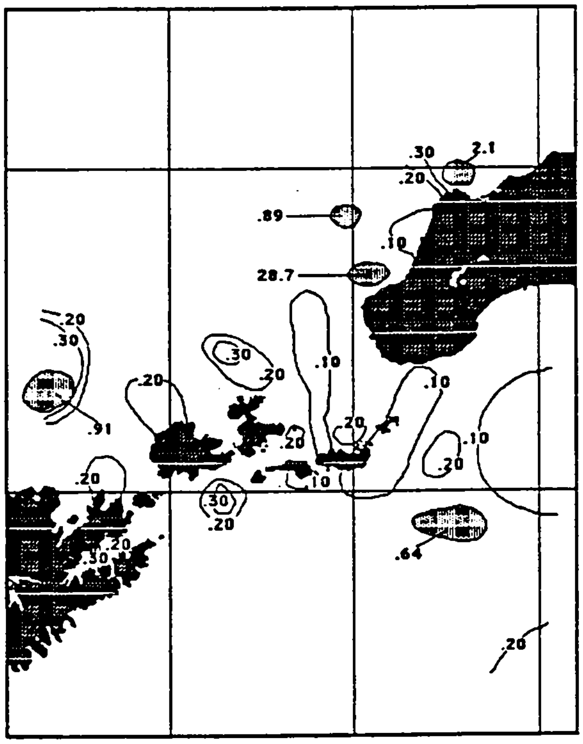


Figure 15. Isolines of total water-column zooplankton abundance (grams/m$^3$) as determined from oblique tows during spring in the Unimak Pass area, Alaska.

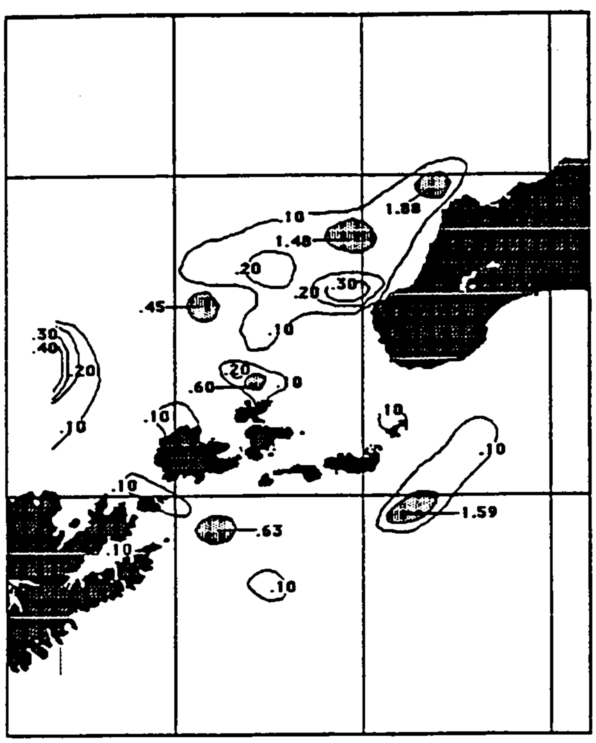


Figure 16. Isolines of total surface zooplankton abundance (grams/m$^3$) as determined by surface tows during spring in Unimak Pass area, Alaska.

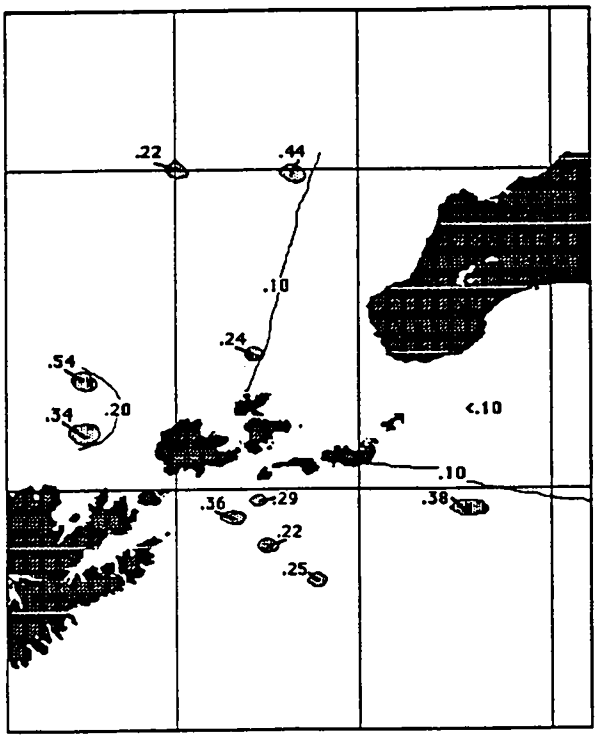


Figure 17. Isolines of euphausiid abundance (grams/m$^3$) in the water-column as determined from oblique tows during fall in the Unimak Pass area, Alaska.

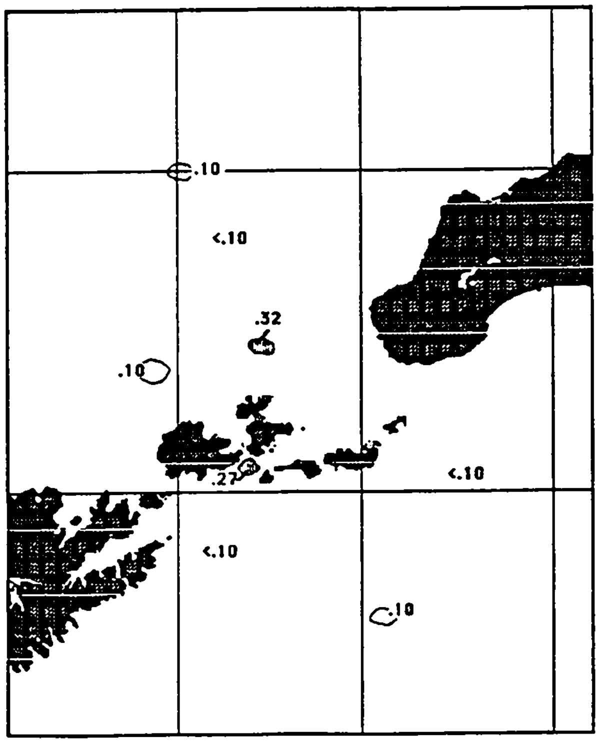


Figure 18. Isolines of euphausiid abundance (grams/m$^3$) at the surface as determined from tucker trawls during fall in the Unimak Pass area, Alaska.

Euphausiids were much less numerous in the surface waters than in the water column. Highest surface catches of eupahusiids were north of Akun Island in Unimak Pass and in Avatanak Strait (Fig. 18).

### Winter

Euphausiids were particularly abundant in the water column in winter in two areas—immediately west and northwest of Unimak Island and among the Krenitzin Islands (Fig. 19). In comparison, they were uncommon in other areas. Their absence from stations far from land was conspicuous.

Euphausiids were abundant at the surface in winter in only a small area immediately southeast of the Krenitzin Islands (Fig. 20); this general area also had high water-column abundances. Their surface biomass was very low elsewhere relative to water-column abundances, and in general, surface and water-column biomass distribution patterns were not similar.

### Spring

Water-column abundances of euphausiids in spring (Fig. 21) were generally lower than they were in winter (Fig. 19), though the locations of highest biomass (i.e., west of Unimak Island, southeast of Unimak Pass proper, and among the Krenitzin Islands) coincided with high-biomass areas in winter. They were not abundant far from land or near shelf breaks.

Locations of surface abundances of euphausiids in spring (Fig. 22) generally paralleled those of subsurface abundances (Fig. 21), and one area of spring surface abundance (southeast of the Krenitzin Islands) coincided generally with the only area of winter surface abundance (Fig. 20).

Converse to the winter vertical distribution, surface biomasses in spring were higher than those in the water column. This reflects expectations, because euphausiids are known for assembling in surface swarms in the spring (Ponomareva 1966).

## Copepods

Knowledge about the distributional abundances of copepods may be important in two ways. First, distribution of copepod biomass may reflect the distributional patterns of primary production, the primary food source of copepods, and thus may indicate something about patterns of upwelling. Second, copepod distributions may help explain some of the distributions of vertebrate predators that depend on them as a food base. The distributions observed in the present study are described below.

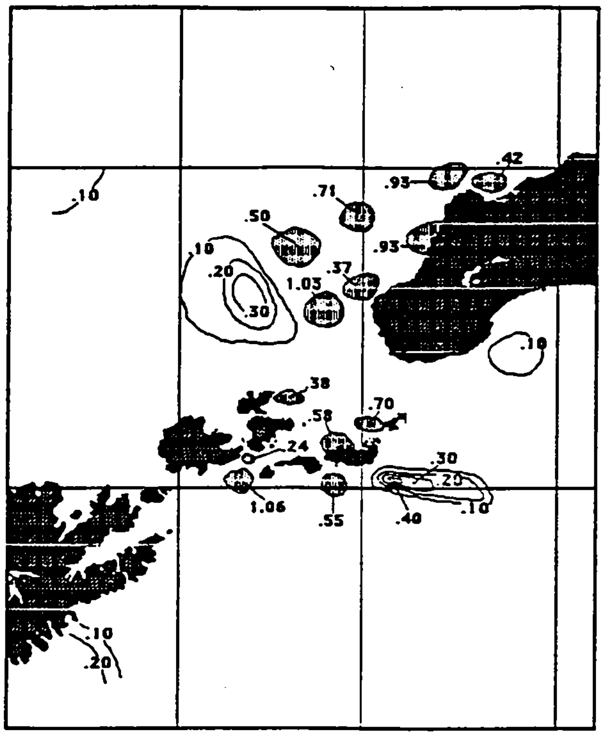


Figure 19. Isolines of euphausiid abundance (grams/m$^3$) in the water column as determined from oblique tows during winter in the Unimak Pass area, Alaska.

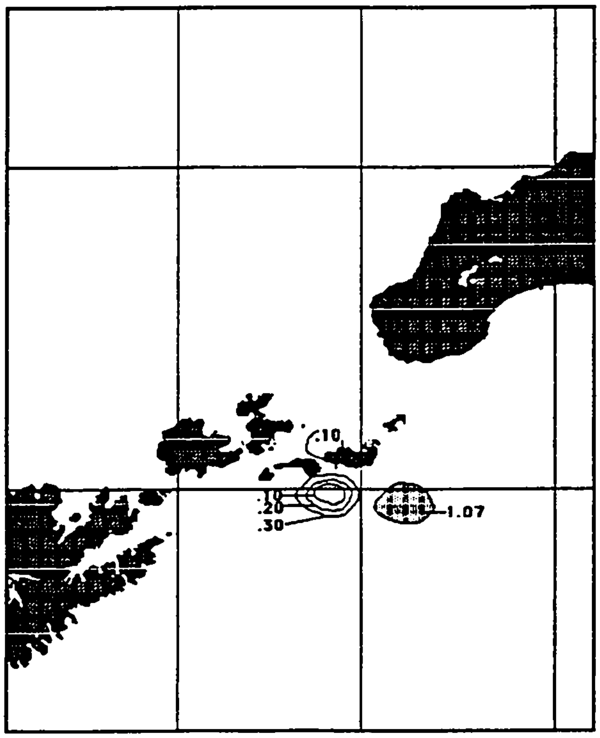


Figure 20. Isolines of euphausiid abundance (grams/m$^3$) at the surface as determined by bongo tows during winter in the Unimak Pass area, Alaska.

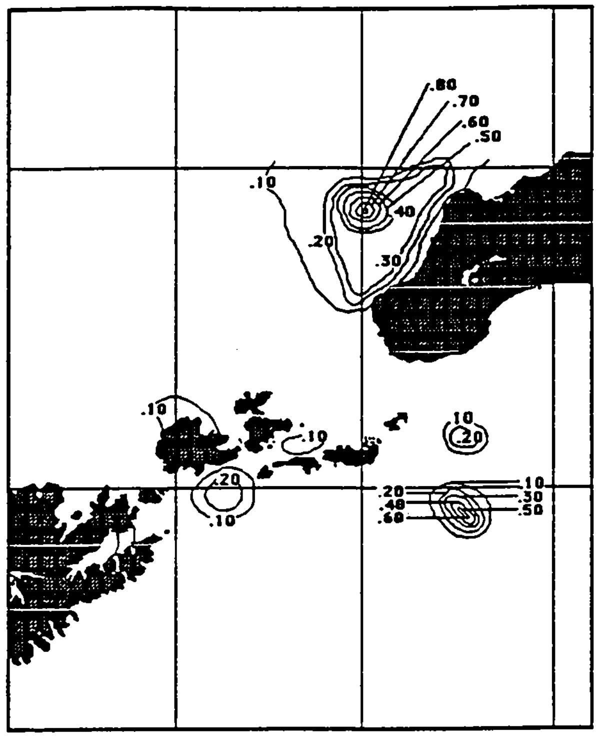


Figure 21. Isolines of euphausiid abundance (grams/m$^3$) in the water column as determined from oblique tows during spring in the Unimak Pass area, Alaska.

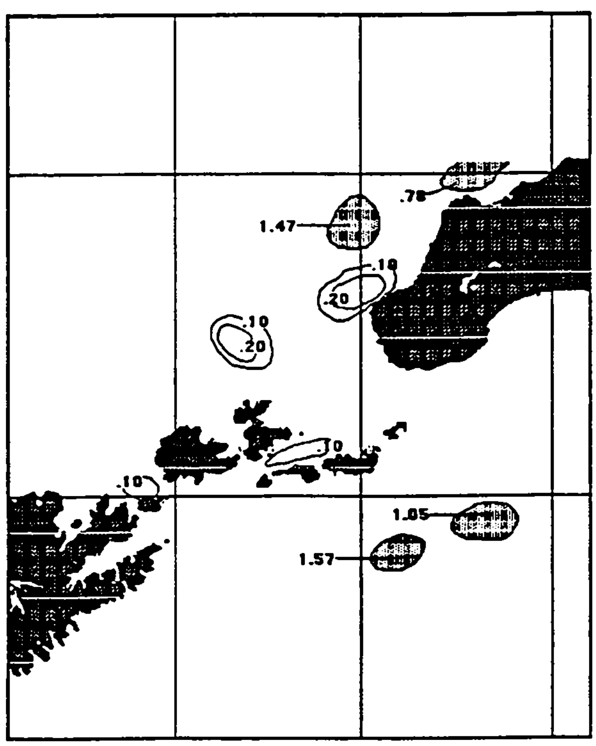


Figure 22. Isolines of euphausiid abundance (grams/m$^3$) at the surface as determined by surface tows during spring in the Unimak Pass area, Alaska.

**Fall**

Both water-column biomasses (Fig. 23) and surface biomasses (Fig. 24) of copepods in the Unimak Pass area during fall were very low in comparison with euphausiid biomass levels. The only samples with biomasses ≈ 0.1 g/m$^3$ were taken at the surface in Unimak Pass north of Akun Island (GAWn), and in the water column north of Akutan Pass (SBW).

**Winter**

Both water-column (Fig. 25) and surface biomasses (Fig. 26) of copepods in the Unimak Pass area in winter were very low in comparison with euphausiid biomass levels. The only samples with average biomasses larger than 1.0 g/m$^3$ were taken at the surface immediately southeast of the Krenitzin Islands, a location that also had high biomasses of surface and water-column euphausiids in winter.

**Spring**

Both water-column (Fig. 27) and surface biomasses (Fig. 28) of copepods in spring were appreciably larger than in fall (see Figs. 23 and 24) or in winter (see Figs. 25 and 26). (Because copepod populations respond quickly to spring phytoplankton blooms, this change was not unexpected.) Water-column biomasses were generally higher than surface levels. Biomasses of copepods in this season approached those of euphausiids, as would be expected because of the more rapid reproductive response capability of copepods to an increase in food supply.

Water column abundances at this time (Fig. 27) were greatest immediately north of Unalaska Island and in Unimak Pass proper. This pattern possibly reflects an influx of nutrient-rich water to this area, perhaps from upwelling or tidal mixing (see Chapter 2: PHYSICAL PROCESSES AND HYDROGRAPHY, this volume). Sites of surface abundance (Fig. 28) were widely scattered in a variety of locations, not with any apparent correlation with water mass distributions or transport patterns.

## DISCUSSION

As we have seen, techniques used for sampling invertebrates selectively captured zooplankton, the presumed major food bases of most vertebrate species of interest in this study. Because the main interest was in the importance of zooplankton as food sources, distributional abundances have been measured in biomass units. The discussions that follow focus on apparent patterns of biomass distribution in space and time, and the likely reasons for these distributions.

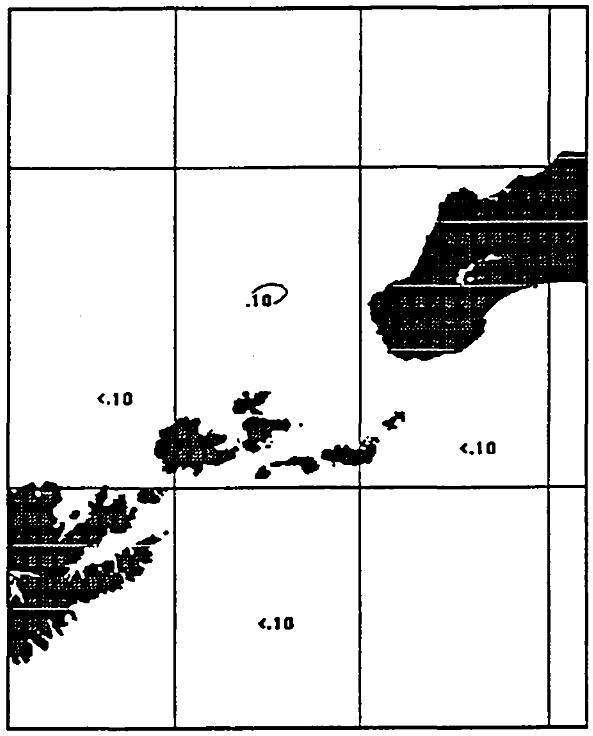


Figure 23. Isolines of copepod abundance (grams/$m^3$) in the water column as determined by oblique tows during fall in the Unimak Pass area, Alaska.

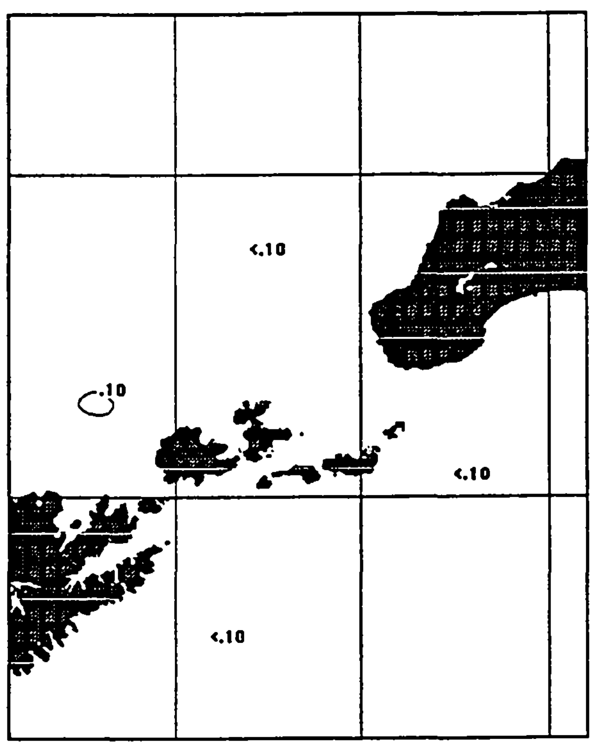


Figure 24. Isolines of copepod abundance (grams/$m^3$) at the surface as determined by tucker trawls during fall in the Unimak Pass area, Alaska.

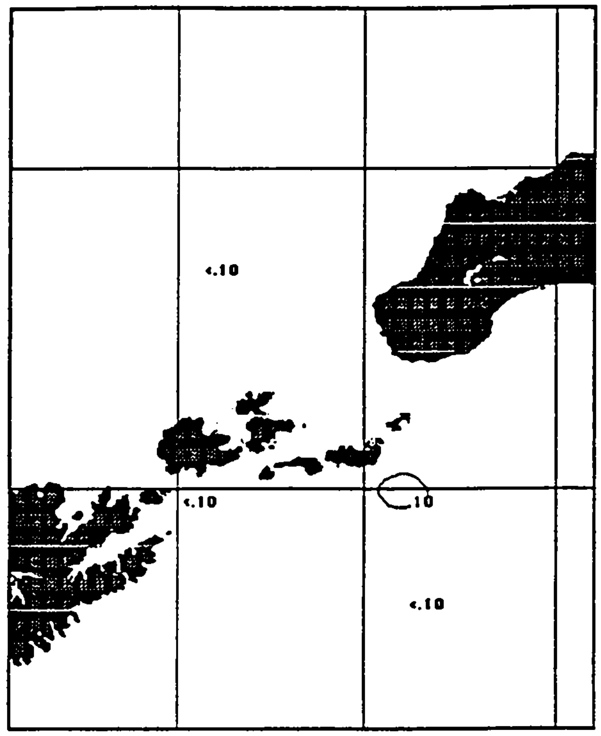


Figure 25. Isolines of copepod abundance (grams/m$^3$) in the water column as determined by oblique tows during winter in the Unimak Pass area, Alaska.

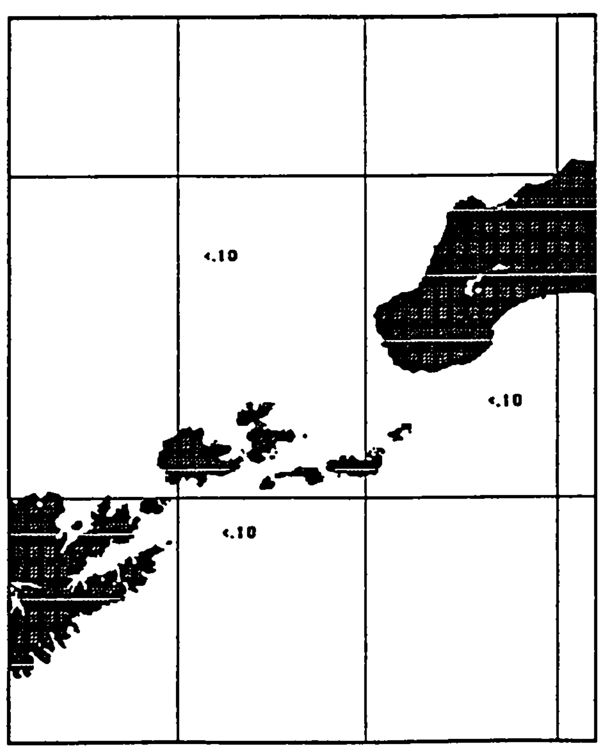


Figure 26. Isolines of copepod abundance (grams/m$^3$) at the surface as determined by bongo tows during winter in the Unimak Pass area, Alaska.

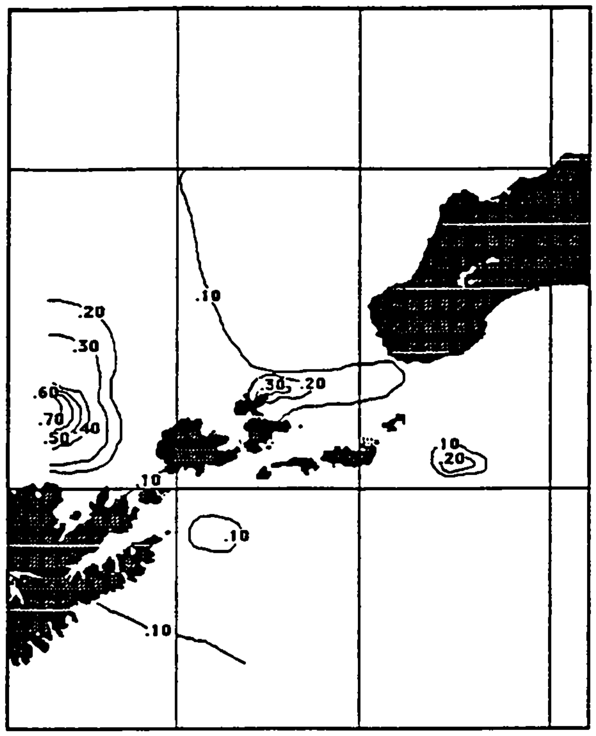


Figure 27. Isolines of copepod abundance (grams/$m^3$) in the water column as determined oblique tows during spring in the Unimak Pass area, Alaska.

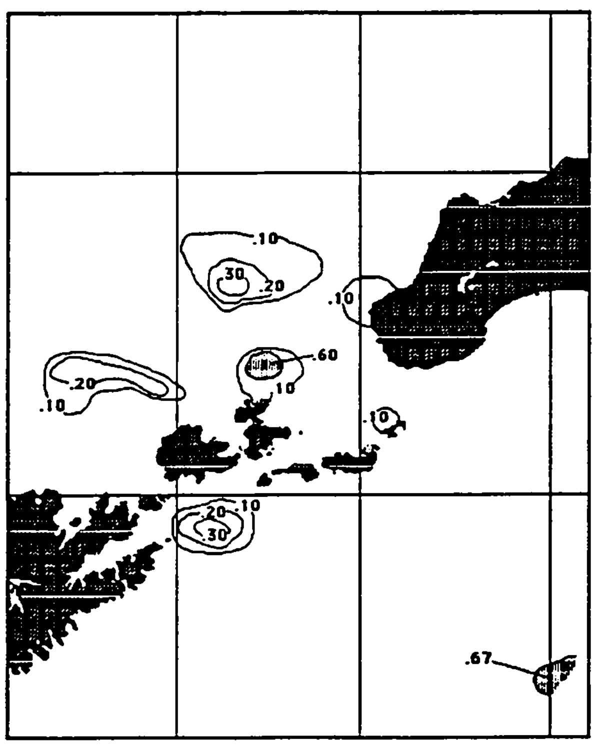


Figure 28. Isolines of copepod abundance (grams/$m^3$) at the surface as determined by surface tows during spring in the Unimak Pass area, Alaska.

### Seasonal Taxonomic Composition

The overwhelming majority of the non-gelatinous zooplankton biomass in fall and winter, and the slight majority in spring, was comprised of euphausiids. (Gelatinous zooplankton, or jellyfish, were exceedingly abundant in spring in the northeast part of the study area, a location known as the "slime bank".) Copepods formed the next most important group.

Seasonal catch patterns for euphausiids were generally as would be expected. In fall and winter, euphausiid abundance in the water column was much higher than at the surface; this pattern reversed in spring. Euphausiids typically gather at the surface in spring to breed (Ponomareva 1966); this phenomenon was presumably what caused the higher spring surface catches and lower water-column catches.

Seasonal variation in copepod abundance reflected the normal spring population growth pattern in subarctic copepods. Copepod biomass was very low in fall and winter, but increased dramatically by the late April-early May sampling period in probable response to increased phytoplankton growth in spring. This same seasonal pattern in copepod abundance has been observed on the adjacent North Aleutian Shelf (Thomson 1987).

### Euphausiid Distribution vs. Oceanographic Processes

Highest biomasses for euphausiids occurred in the fall around the Krenitzin Islands with occasional high biomasses in deeper water. The only region of low biomass was the Alaska Coastal Water (north and south) zone around Unimak Island. In winter, euphausiid biomass was concentrated in shelf areas within 50 km of land, mostly in the immediate vicinity of Unimak Pass (west of Unimak Island, in the Krenitzin Islands, and southeast of the Krenitzins). Areas farther offshore and near the shelf breaks had, in comparison, very low euphausiid populations.

Reasons for this pattern of distribution are not clear, particularly since winter bird diets in the area (see Chapter 5: MARINE BIRD ABUNDANCE AND HABITAT USE, this volume) suggest that the euphausiid community is dominated by *Thysanoessa inermis*, a species thought to be affiliated more with oceanic areas than with shelf waters (see Current State of Knowledge, this chapter). Perhaps the vertical mixing that appears to bring water from off the the oceanic regime into the Unimak Pass-North Aleutian Shelf area (see Chapter 2: PHYSICAL PROCESSES AND HYDROGRAPHY, this volume) plays a role in concentrating oceanic euphausiids in this shelf area.

In spring, euphausiid biomass distributions were remarkably similar to the winter distributions. Concentrations were on the shelf: west of Unimak Islands, among the Krenitzin Islands, and immediately southeast of Unimak

Pass. The few bird stomachs that contained euphausiids in spring again contained the oceanic species *T. inermis*.

### Copepod Distributions vs. Oceanographic Processes

In fall and winter, copepods were so scarce in samples that no strong inferences about distributional patterns were possible. There was some indication, however, that copepods were more abundant near the Unimak Pass-Krenitzin Islands area (up to 50 km from shore) than elsewhere.

In spring, copepod biomasses were larger and patterns of distribution clearer. Water-column biomass was greatest immediately north of Unalaska Island, at the expected point of entry into the study area of upwelled, nutrient-rich water from the west (see Chapter 2: PHYSICAL PROCESSES AND HYDROGRAPHY, this volume); a less prominent surface concentration was also noted in this area. Smaller water-column and surface concentrations also appeared in the Unimak Pass-Krenitzin Islands area, which overlapped a winter-spring concentration area for euphausiids as described above.

Samples in the extreme southeastern corner of the study area, beyond the Gulf of Alaska shelf break, showed an anomalously high copepod concentration in comparison with that of shelf-edge waters elsewhere in the study area. This could have been caused by conditions in Pacific oceanic waters that were impinging on the shelf.

## RECOMMENDED FURTHER RESEARCH

The data collected during the present investigations have revealed that, throughout most of the study area and during most of the cruises, euphausiids were the most abundant prey available for marine birds and mammals. The diet information collected also indicated that the seabirds present were preying predominantly on this group. The major gap in our zooplankton sampling is the absence of summer sampling. In the adjacent NAS region, mid-summer was a period of high densities of euphausiids and thus seabirds, but, as has been seen in other comparisons, trends can be very different in the Unimak and NAS areas. Summer sampling would be required to fill this information gap.

## ACKNOWLEDGEMENTS

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We thank CDR Taguchi, who found ways to accommodate our innumerable trips through (and residence in) all passable passes in the Krenitzin Islands. LT Brian Hayden (FOO) made arrangements for all our requests and accommodated last-minute changes in plans, allowing us to obtain all our samples where and when we wanted them.

Denis Thomson provided valuable suggestions for the conduct of this study and insights based on his knowledge of the adjacent North Aleutian Shelf. Dan Daugherty, the Chief Biological Survey Technician of the R/V Miller Freeman provided tremendous assistance during all nighttime sampling. The completeness of our survey would not have been possible without his assistance. Ruth Reigel sorted the fall cruise samples. Michael Bradstreet developed the shipboard procedures for estimating biomasses of the major prey. Sue Saupe also provided tremendous aid in sampling and sorting during the winter cruise. Dale Herter and Michael Bradstreet helped with sorting during the winter and spring cruises.

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